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The Effects of Pesticides on Species of Non-target Heteroptera Inhabiting Cereal Fields in Southern England

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Abstract: The effects of pesticides on beneficial predatory arthropods have been widely studied; this paper however deals with their effects on Heteroptera, an important beneficial insect group and food source for farmland birds. Field trials were used to evaluate pesticide effects under realistic conditions of application on a commercial arable farm and compared with previously published laboratory findings. Fungicides were found to produce very low levels of mortality, not significantly different from control treatments. Aphicides varied in their impact, producing non-significant to highly significant mortality levels. The likely ecological impact of pesticides on various heteropteran groups found within the field and field boundary is discussed.

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1 INTRODUCTION

Treatments for aphid pests (Hemiptera: Homoptera) constitute the major market for insecticides in the UK. Side-effects against non-target species of beneficial Hemiptera, including plant bugs (Hemiptera: Heteroptera), are a potentially undesirable consequence of aphicide use. Owing to their importance as biological control agents in glasshouses and orchards, many studies have assessed the impact of insecticides on important beneficial, non-target hemipteran species, including generalist predators of the genus *Anthocoris* (Heteroptera: Cimicidae).[1–7] Within cereal crops, the low densities of *Anthocoris* spp. and other species of predatory Heteroptera have probably contributed to their exclusion from the numerous investigations of insecticide side-effects on beneficial arthropods in cereals.

Non-pest phytophagous species of Heteroptera may also be present within cereal fields. Some species of Miridae can occur in high densities, and the most common of these in southern England is *Calocoris norvegicus* (Gmelin).[8,9] The effects of pesticides on this species have not previously been quantified because it has not been regarded as either a pest of arable crops or a beneficial invertebrate. However, Heteroptera are considered to be an important component of the so-called 'chick food insects'[10] and are to be found in the diet of many bird species of arable land such as *Perdix perdix* L.,[11–13] *Alectoris rufa* L.,[11] *Phasianus colchicus* L.,[14] *Corvus monedula* L.,[15] *Parus major* L.[16] and *Pyrrhocorax pyrrhocorax* L.[17] The definition of 'beneficial' now extends to species of importance in the feeding ecology of farmland vertebrates such as farmland birds.[18]

Herbicides are normally applied before Heteroptera disperse into the field from their overwintering sites in the vegetation of field boundaries.[9] However, numerous fungicides and insecticides may be used during the

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period when *C. norvegicus* nymphs and other heteropteran species are present in the field itself, especially when chemicals are applied late in the season. An initial laboratory screening of a wide range of pesticides for their direct, short-term toxicity against *C. norvegicus* nymphs found fungicides to exhibit only low toxicity, while insecticides could be divided into two groups, with high and low toxic effects respectively.[19] From this procedure, a number of insecticides and fungicides were selected for further field studies in which the routes of exposure to the chemical would more closely represent those experienced by Heteroptera under field conditions. This paper presents the findings of these field experiments.

2 MATERIALS AND METHODS

2.1 Fungicides

Three fungicides commonly used in disease control programmes in UK cereal crops, tridemorph, propiconazole and prochloraz were tested with a water control (Table 1). The treatments were applied to 12 plots of winter wheat, cv. Galahad, (6 m wide × 75 m long) within the field headland on a commercial arable farm on the Hampshire/Dorset border in southern England. All the cereal headland plots had the same aspect, gradient and soil type, and ran consecutively adjacent to the field boundary which was formed by a mixed thorn hedgerow. The experimental plots were placed in the first 6 m of cereal between the crop edge and the tramlines running parallel to the field edge. This part of the headland was selected as it is a preferred feeding site of partridge chicks foraging for insects[11] and has been shown to contain relatively high densities of Heteroptera compared to field areas 50 m away from the boundary.[20]

Each chemical application was replicated three times and treatments were allocated to the 12 headland plots in a random sequence (Fig. 1). No buffer plots were possible between the treated plots as this would not have allowed all treatments to have had a similar boundary type and aspect. The treatments were applied with a self-propelled Chafer Tramliner SP sprayer, fitted with a 24-m spray boom and 72 cone-jet nozzles (Chafer No. 3 (red)). Operating pressure was 1·7 bar and the chemicals were applied at conventional field rates in water at 200 litre ha^{-1}, achieved with a 10 km h^{-1} forward speed. Insect samples were collected using a Dietrick vacuum insect sampler[21] on three dates, two post- (+5 (22 June 1989) and +15 (3 July 1989) days after treatment) and one pre-spray (−3 days (14 June 1989)). On each date, samples were taken from two positions, at the field edge within the wild flora next to the base of the hedge and 3 m into the cereal headland. Five suction samples of 0·5 m^2, each comprising five 0·1 m^2 sub-samples, were collected at each site along a transect parallel to the field edge within the middle 25 m of each plot, therefore allowing a buffer strip within the treatment plots of 50 m between adjacent sampling areas. Heteroptera were sorted into four groups; *Calocoris norvegicus*, predatory species (*Nabis* spp., *Anthocoris* spp.), grass-feeding Stenodemini (*Leptopterna dolabrata* (L.), *Notostira elongata* (Geoffroy), *Stenodema* spp.) and other Heteroptera, comprising all species not already categorised in the other three groups (see Table 3). All four groups were also combined to form a fifth group, total Heteroptera.

2.2 Insecticides

The experimental design used to quantify the extent of the activity of four insecticides against non-target Heteroptera was similar to that in the fungicide experiment but was conducted over three fields of winter wheat, cv. Avalon, on the same farm. In each field the treatments

TABLE 1
Details of Active Ingredients and Doses of Products used in the Field Experiments.[a]

	Product	*g AI litre*$^{-1}$	*Formulation type*
Fungicides			
Tridemorph	'Bardew'	750	EC
Propiconazole	'Tilt' 250-EC	250	EC
Prochloraz	'Sportak'	400	EC
Insecticides			
Phosalone	'Zolone'	350	EC
Demeton-S-methyl	'Metasystox'-55	580	EC
Dimethoate	'Rogor' E	400	EC
Pirimicarb	'Aphox'	500	SG

[a] All diluted in water at 200 litre ha^{-1}.

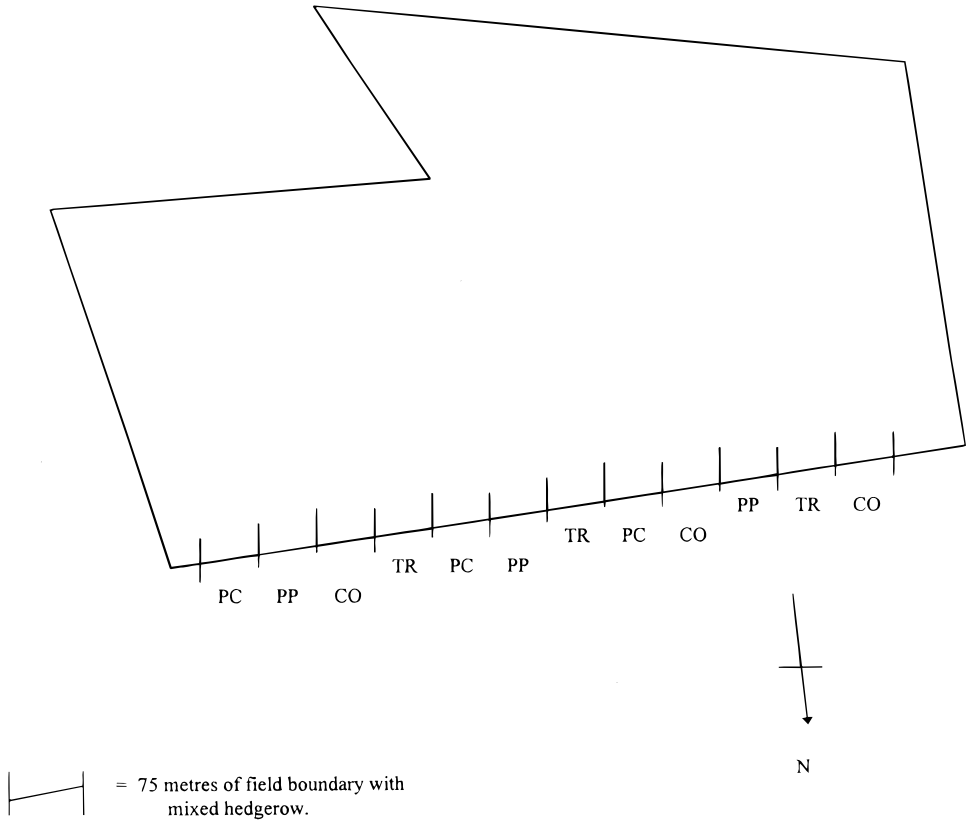

Fig. 1. Position and aspect of fungicide-treated plots on the study farm, Hampshire, 1989. CO = Control; PC = Prochloraz; PP = Propiconazole; TR = Tridemorph.

were applied to 6 m wide × 100 m long lengths of cereal in the outer headland, which again ran consecutively adjacent to hedgerows. All fields had similar soil types and gradient. Four insecticide treatments, phosalone, pirimicarb, demeton-S-methyl and dimethoate, and a water control were used (Table 1) and were replicated three times in each field (Fig. 2). The treatments were allocated to 15 headland plots per field in a random sequence and were applied with a tractor-mounted sprayer at conventional field rates (Table 1) in water at 200 litre ha^{-1}. Suction samples were collected on two dates, pre-application (−2 days (29 June 1987)) and post-spray (+7 days (8 June 1987)), at 3 m into the cereal outer headland. Five suction samples of 0·5 m^2 each containing five 0·1 m^2 sub-samples were collected at each site, the samples being taken at random along a transect 3 m from the crop edge. While, again, no buffer areas were possible between plots, the samples were collected within the middle 50 m of each plot, allowing a 50 m treated buffer strip between adjacent-sampling areas. The collected Heteroptera were sorted for analysis as described above.

2.3 Statistical analysis

From the fungicide field trial, mean numbers of each heteropteran group were calculated for each plot on each sampling date and these were then transformed (log $(n + 1)$) to stabilise the variance.[22] Before analysis, pre-treatment transformed data were subtracted from post-treatment ones to adjust for initial conditions. The differences were analysed by a split-plot analysis of variance (ANOVA) with 3 & 8 degrees of freedom for treatment, 3 & 8 degrees of freedom for treatment × distance within plot interaction and 1 & 8 degrees of freedom for distance within plot. The analysis was carried out using Genstat 5.[23] If no significant treatment × distance interaction occurred, the ANOVA was used to compare differences between pre-treatment and post-treatment (+5 days) and pre-treatment and post-treatment (+15 days) at 0 m and 3 m together. If an interaction was found, distances were treated separately. If significant differences between treatments occurred, ones between pairs of treatments were tested using Students Least Significant Difference (LSD) ($P > 0{\cdot}05$).

For the insecticide trial, mean numbers of each heteropteran group were calculated from the plots and these were then transformed (log $(n + 1)$) as above. Before analysis, pre-treatment transformed data were subtracted from post-treatment ones to adjust for initial conditions. A two-way ANOVA by field and treatment was carried out on these plot differences; if significant

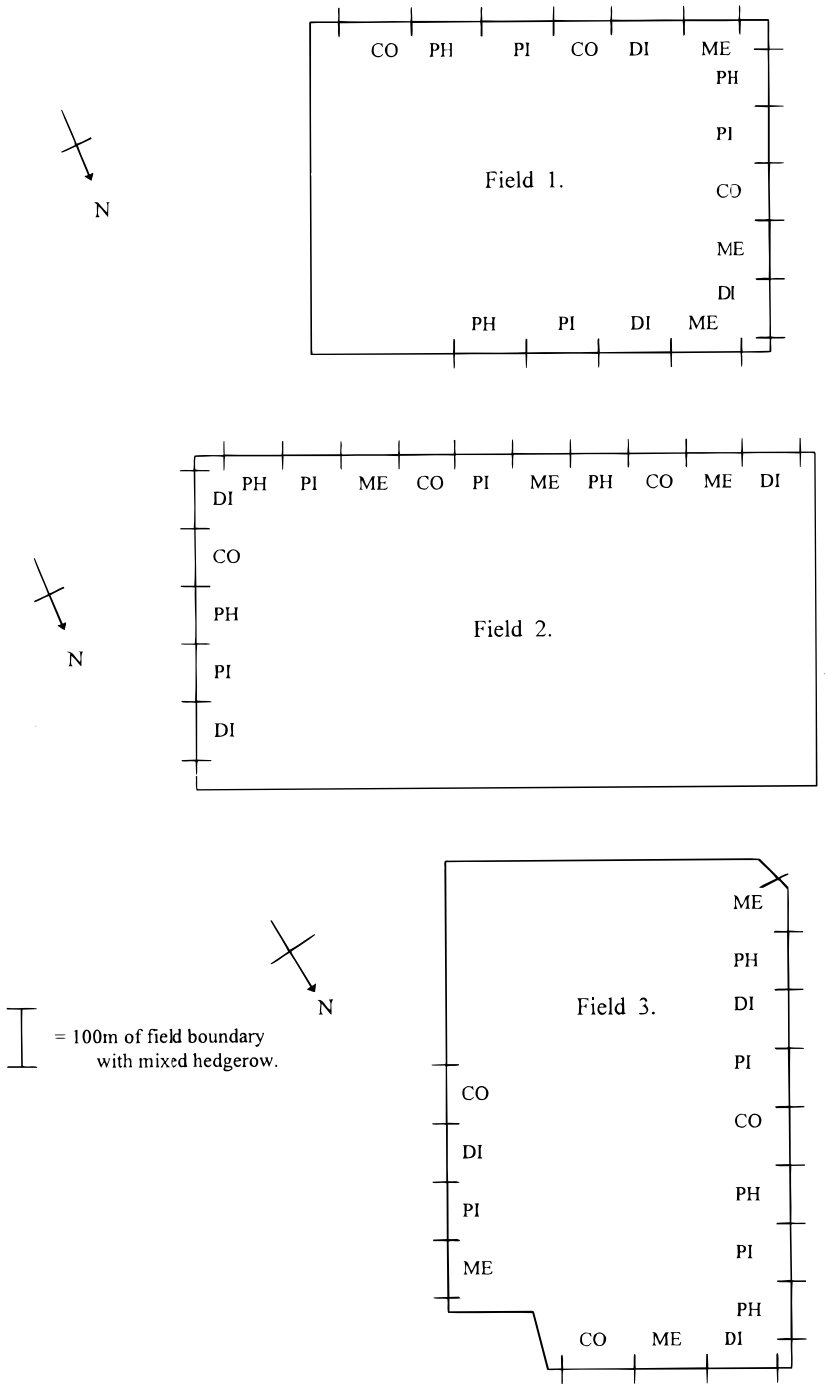

Fig. 2. Position and aspect of insecticide-treated plots on the study farm, Hampshire, 1987. CO = Control; PI = Pirimicarb; PH = Phosalone; ME = Metasystox; DI = Dimethoate.

field × treatment interactions occurred, the individual fields were reanalysed separately using a one-way ANOVA with 4 & 10 degrees of freedom, otherwise the effect of treatment was assessed on 4 & 30 degrees of freedom. As above, pairwise differences between treatments were examined by LSD only if the overall test for treatment differences was significant.

Analysis was carried out on the five heteropteran groups, *Calocoris norvegicus*, predatory species, Stenodemini, other Heteroptera and total Heteroptera.

3 RESULTS

3.1 Fungicides

In the two-way ANOVA, no significant treatment × distance interactions were detected, therefore the two distances were not separated in analysis for treatment differences. No significant treatment differences were detected in the post-treatment (+5 days) minus pre-treatment or the post-treatment (+15 days) minus pre-

treatment data between any of the chemicals or between the control for any of the heteropteran groups studied (Fig. 3).

Only one group, the 'other Heteroptera', exhibited a significant between-habitat difference, being more numerous at the field edge (0 m) compared to the crop edge (3 m). The groups of predatory Heteroptera and the Stenodemini also exhibited a similar but non-significant habitat preference. *C. norvegicus*, the overall dominant species, strongly favoured the cereal habitat compared to the non-crop field edge; however this difference was non-significant (Table 2; Fig. 4). While there were few significant differences between habitats, all the 26 heteropteran species found occurred in the field boundary, with 12 out of these 26 species being found only in this habitat, the remaining 14 species also occurring at 3 m in the crop (Table 3).

3.2 Insecticides

No significant field × treatment interactions were found

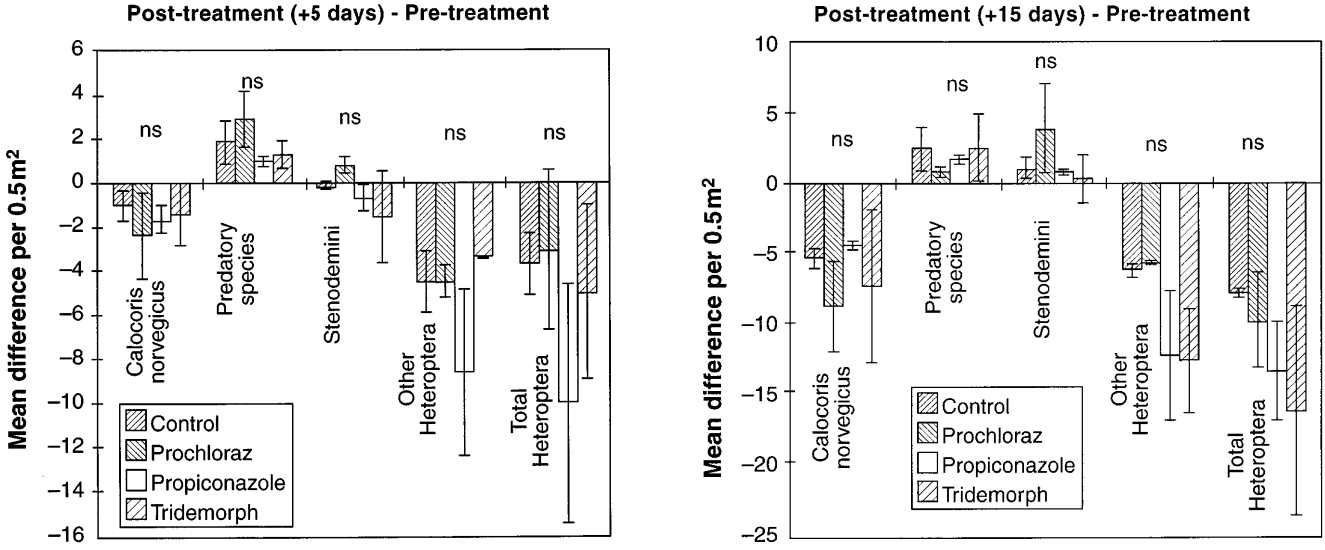

Fig. 3. Mean differences between pre-treatment and post-treatment (+5 & +15 days) sampling of Heteroptera (±S.E.) per 0·5 m^2 from within the combined distances (0 m & 3 m) in a field of winter wheat sampled in the replicated fungicide experiment (d.f. 3 & 8) collected in June on the study farm in southern England. Differences between treatments at the $P > 0{\cdot}05$ significance level are signified by a different letter, no significant differences between any treatments are signified by ns.

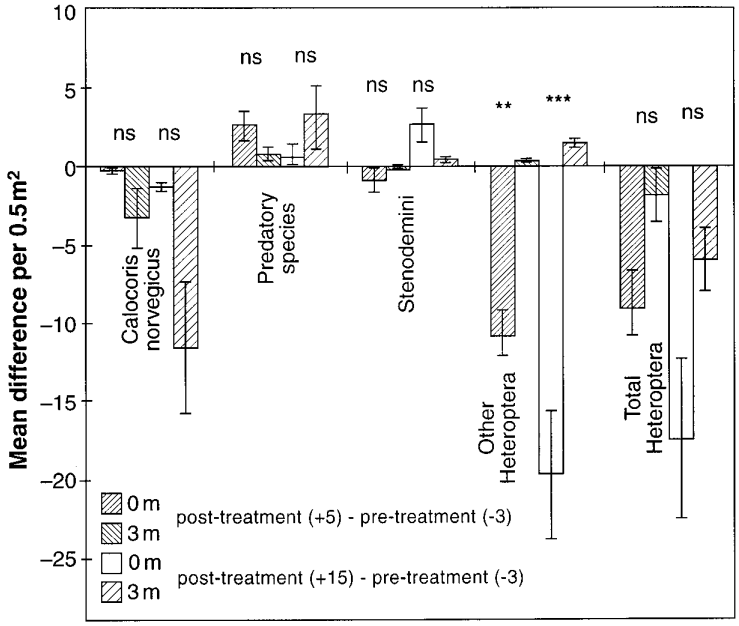

Fig. 4. Mean differences between pre-treatment and post-treatment (+5 & +15 days) sampling of Heteroptera (±S.E.) per 0·5 m^2 and between the two distances 0 m and 3 m in a field of winter wheat sampled in the replicated fungicide experiment (d.f. 1 & 8) collected in June on the study farm in southern England. ($P > 0{\cdot}05$ = *, $P > 0{\cdot}01$ = **, $P > 0{\cdot}001$ = ***, no significance = ns).

TABLE 2
Mean Numbers of Heteroptera (±S.E.) per 0·5 m^2 Sampled from the Boundary (0 m) and within the Cereal Headland (3 m) in the Field of Winter Wheat used for the Replicated Fungicide Experiment on the Three Sampling Dates

	Pre-treatment (−3 days)		*Post-treatment (+5 days)*		*Post-treatment (+15 days)*	
	0 m	*3 m*	*0 m*	*3 m*	*0 m*	*3 m*
Calocoris norvegicus	2·43 (±0·75)	19·10 (±6·50)	2·33 (±0·83)	15·93 (±5·04)	1·19 (±0·42)	7·67 (±2·67)
Predators	2·83 (±0·45)	1·63 (±0·89)	5·45 (±1·71)	2·50 (±1·34)	3·25 (±1·44)	5·04 (±2·68)
Stenodemini	2·88 (±1·93)	0·25 (±0·12)	2·05 (±0·81)	0·36 (±0·17)	5·55 (±2·99)	0·74 (±0·26)
Other Heteroptera	34·41 (±7·08)	0·51 (±0·18)	23·66 (±6·61)	0·88 (±0·24)	14·84 (±3·72)	2·04 (±0·34)
Total Heteroptera	42·81 (8·99)	21·51 (±6·09)	33·81 (±5·41)	19·72 (±3·93)	24·74 (±3·97)	15·61 (±4·03)

for the groups *Calocoris norvegicus*, predatory Heteroptera or total Heteroptera, but significant interactions were found between fields for two groups, Stenodemini and other Heteroptera. As a result each field was considered separately for these two groups.

Calocoris norvegicus was numerically the dominant heteropteran in the headlands of all three cereal fields. While all mean plot densities decreased post-treatment, the reductions were significantly greater in both the demeton-S-methyl and the dimethoate plots compared to the phosalone- and pirimicarb-treated plots (Fig. 5). There was no significant difference between any treatment and the control.

There were no significant differences in numbers of predatory Heteroptera between any treatments (Fig. 5). While numbers were very low in all plots, a small increase did occur in many plots after treatment.

For the group total Heteroptera, as with *C. norvegicus*, greater reductions in numbers occurred after treatment in both the demeton-S-methyl and the dimethoate plots compared to the phosalone- and pirimicarb-treated plots, but with only the pirimicarb plots exhibiting a significant reduction. Again there was no significant difference between the control and the other treatments. These results were caused by the large numerical dominance of *C. norvegicus* over all the other heteropteran groups (Fig. 5).

Treatment effects on the Stenodemini were compared on an individual field basis (Fig. 6). In Field 1, numbers increased slightly within the control, phosalone- and pirimicarb-treated plots after treatment and decreased in both the demeton-S-methyl and dimethoate plots, the differences between the former three and latter two treatments being significant. In Fields 2 and 3 no significant differences between plot means were detected.

The group 'other Heteroptera', also exhibited significant field × treatment interactions (Fig. 7). Plot means were generally low in all treatments and as a result no significant differences were found in Fields 2 and 3. In Field 1, all plots exhibited small non-significant mean changes, with the exception of the pirimicarb-treated ones, in which mean numbers significantly increased after treatment compared to all others.

TABLE 3
Presence (+) or Absence (−) of Species of Heteroptera found at the Field Edge (0 m) and at 3 m into the Field

	0 m	*3 m*
Calocoris norvegicus (Gmelin)	+	+
Predators *Nabis ferus* L.	+	+
Anthocoris nemorum L.	+	+
Stenodemini *Leptopterna dolabrata* (Fallen)	+	+
Notostira elongata (Geoffroy)	+	+
Stenodema spp.	+	−
Other species found at 0 m only		
Scolopostethus spp.	+	−
Taphropeltus contractus (Herrich-Schaeffer)	+	−
Amblytylus nasutus (Kirschbaum)	+	−
Dicyphus spp.	+	−
Heterotoma merioptera (Scopoli)	+	−
Liocoris tripustulatus (Fabricius)	+	−
Lygus pabulinus L.	+	−
Lygus rugulipennis (L) Poppius	+	−
Piesma maculata Costa	+	−
Cyllecoris histionicus (L.)	+	−
Sehirus bicolor (L.)	+	−
Other species found at 0 m and 3 m		
Calocoris sexguttatus (Fabricius)	+	+
Himacerus mirmicoides (Costa)	+	+
Orthonotus rufifrons (Fallen)	+	+
Plagiognathus arbustorum (Fabricius)	+	+
Capsus ater (L.)	+	+
Pithanus maerkeli (Herrich-Schaeffer)	+	+
Deraecoris ruber (L.)	+	+
Psallus spp.	+	+
Palomena prasina L.	+	+

4 DISCUSSION

This study, in particular the insecticide trial, encountered problems common to many large-scale field trials with replicated plots. The advantage of having similar boundary vegetation had to be offset against having to place the plots on two or more sides of a field, resulting

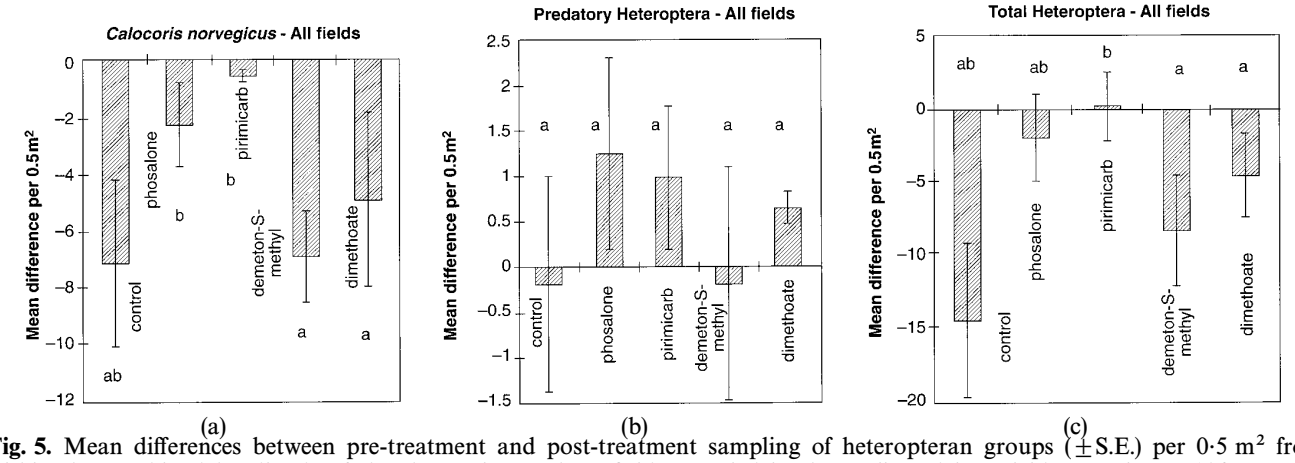

Fig. 5. Mean differences between pre-treatment and post-treatment sampling of heteropteran groups (±S.E.) per 0·5 m^2 from within the combined headlands of the three winter wheat fields sampled in the replicated insecticide experiment (d.f. 4 & 30) collected in June on the study farm in southern England. Differences between treatments at the $P > 0{\cdot}05$ significance level are signified by a different letter.

in a possible effect of aspect on faunal diversity, either directly due to temperature or indirectly due to differences in the flora. Buffer plots between the treatment plots would have been ideal, but the need to have large plots to reduce the possible risk of heteropteran movement between sampling sites was an important consideration. Collecting samples from the centre of each treatment plot and thus allowing a treatment buffer

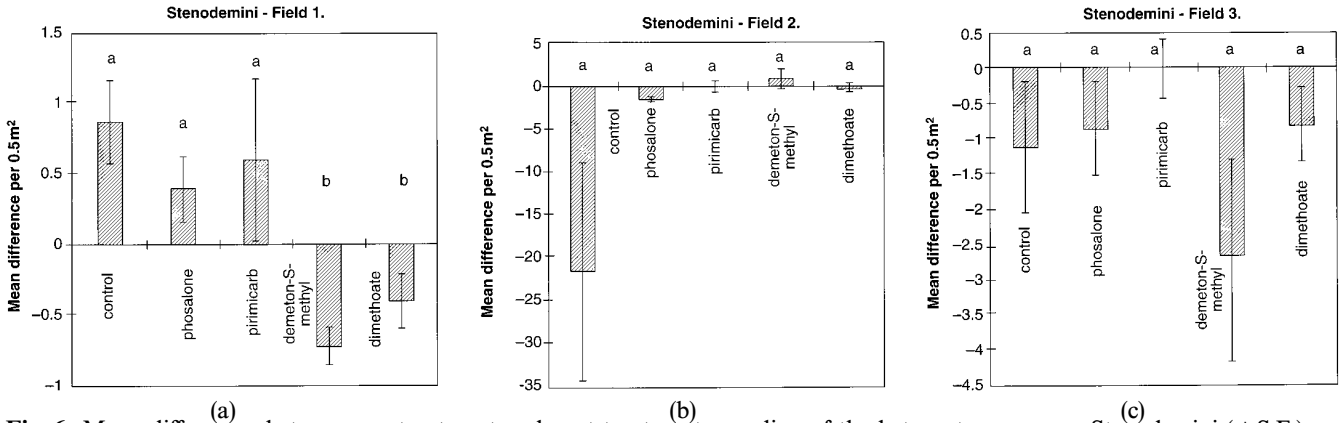

Fig. 6. Mean differences between pre-treatment and post-treatment sampling of the heteropteran group, Stenodemini (±S.E.) per 0.5 m^2 from within the individual headlands of the three winter wheat fields sampled in the replicated insecticide experiment (d.f. 4 & 10) collected in June on the study farm in southern England. Differences between treatments at the $P > 0{\cdot}05$ significance level are signified by a different letter.

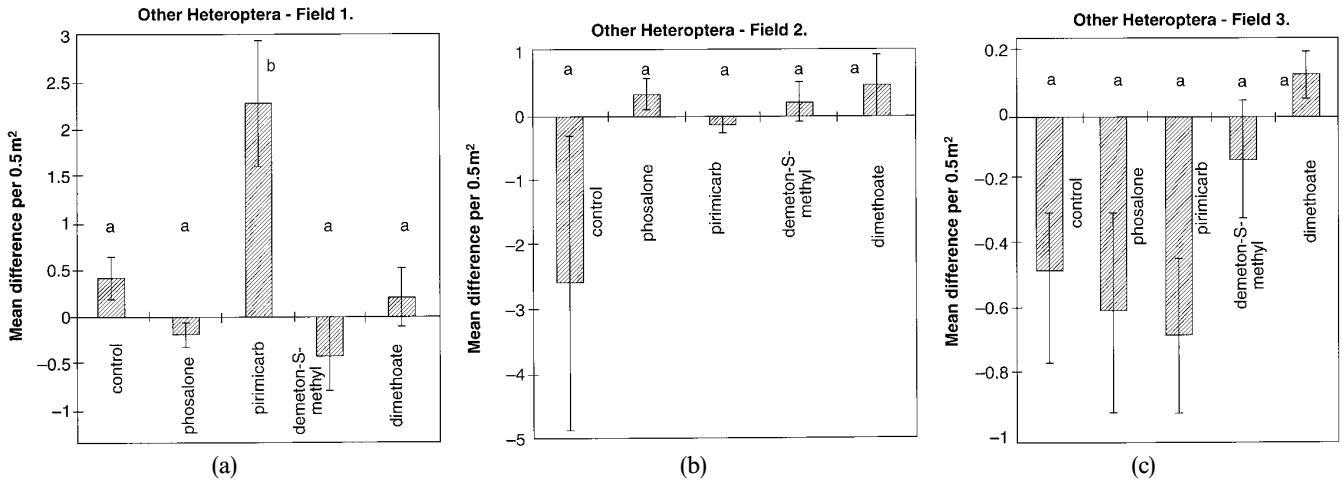

Fig. 7. Mean differences between pre-treatment and post-treatment sampling of the group 'other heteroptera' (±S.E.) per 0·5 m^2 from within the individual headlands of the three winter wheat fields sampled in the replicated insecticide experiment (d.f. 4 & 10) collected in June on the study farm in southern England. Differences between treatments at the $P > 0{\cdot}05$ significance level are signified by a different letter.

should have minimised movement from adjoining treatments.

The results from these field trials confirmed those found in laboratory screening trials for the effects of pesticides on *C. norvegicus* nymphs[19] and also quantified the field effects of fungicides and insecticides on a greater range of non-target Heteroptera. When applied at field dose-rates to cereal field-dwelling Heteroptera, the three commonly used fungicides caused no significant reductions in numbers. No heteropteran species are recorded as being obligate mycetophages, therefore indirect effects *via* depletion of fungal food resources would not be expected.

While these results showed that many fungicides will have no significant effect on heteropteran populations, specific formulations have been shown to have insecticidal properties that significantly reduce populations of beneficial arthropods in cereal fields. For example the organophosphate fungicide pyrazophos possesses significant insecticidal properties to a range of non-target species.[24–29] Sub-lethal doses of fungicides have also been shown to affect some invertebrates.[30]

However, as important as this study may be in examining the impacts of fungicide use, it is perhaps also important in showing the potential diversity within this heteropteran group. All heteropteran species found occurred in the field boundary and 12 out of these 26 species were found only in this non-cropped habitat. While 14 out of the 26 species were found 3 m into the cereal crop (Table 3), *C. norvegicus*, the numerically dominant species in both habitats, was the only species to feed on the cereal itself with 85% of the sampled population occurring within the crop (Table 2, Fig. 4).

Insecticides are regularly used in cereal fields at a time when *C. norvegicus* and many other heteropteran species are active within the crop. The differing levels of mortality found between insecticide treatments in this study and many others[4–7,18–22, 24–36] indicate that the choice of active ingredient could have an important impact on the abundance of Heteroptera and thus their availability as food for farmland birds.

In both the laboratory[19] and this field study (Figs 5, 6 & 7), the use of the two chemicals phosalone and pirimicarb resulted in only small non-significant changes in number of *C. norvegicus* and other Heteroptera, whereas the use of demeton-S-methyl and dimethoate caused larger and often significant short-term reductions. High levels of mortality have also been recorded in the IOBC/WPRS, 'Joint Pesticide Testing Programmes'[4–7] when dimethoate was tested against *Anthocoris* spp. using the recommended field rate. Similar results have been found for other non-target species eaten by young birds, including Carabidae and Lycosidae when treated with aphicides applied at the recommended dose rates approved for summer use in the UK.[31] Pirimicarb was not toxic, with very low mortality levels being found in laboratory and field tests among both carabids and lycosids. However dimethoate was found to be very toxic to the carabid *Pterostichus melanarius* (Illiger), resulting in high levels of mortality, and it caused varying levels of mortality to spiders. Dimethoate has also been found to reduce densities of most non-target arthropod groups in cereals[32] and to have a considerable impact on densities of sawfly larvae[33,34] (Symphyta: Tenthredinidae), another important Galliform chick-food group.[10]

While the laboratory studies only examined mortality following contact, any estimates of impact in the field were likely to be as a result of exposure following direct contact during spraying and by contact with spray residues on vegetation surfaces. Dimethoate has been found to be toxic to carabids, resulting in varying levels of mortality for at least six to nine days on cereal foliage and soil,[35] and spray deposits from both demeton-S-methyl and dimethoate on winter wheat flag leaves remained significantly toxic to beneficial invertebrates for four to seven days.[36] Some compounds such as dimethoate are also known to have systemic properties which may have contributed to the high levels of mortality observed, especially among sap-feeding Heteroptera.

No species occurred only within the crop itself, but some chemicals could potentially have a detrimental impact on populations of certain species such as the heteropteran predators which occurred in low numbers in both habitats (Table 2). Significant long-term reductions of species such as *C. norvegicus*, which has populations of both nymphs and adults found predominantly within the crop during the summer rather than in the field boundary, are also likely (Table 2 & Fig. 4). Like many other heteropteran species, *C. norvegicus* is univoltine and the nymphal population of this species is found mainly concentrated within the headland zone within the first 6 m from the field boundary.[37] The low mobility of nymphs suggests that large reductions in densities following treatment with insecticides could not readily be replaced by dispersal from surrounding unsprayed areas and could affect population levels over large temporal and spatial scales.

Within the field some reductions in non-target arthropod densities following pesticide applications will be inevitable. However, this study shows the importance of correct spraying procedures to avoid pesticide drift into the boundaries where heteropteran diversity was greatest (Tables 2 & 3; Fig. 4) and the potential value of keeping insecticides out of a headland zone (at least 6 m wide), which has been shown to act as a buffer against any potential drift into the field edge.[38–41]

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